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**Bauer et al.**

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(54) **HARDWARE CONSUMPTION ARCHITECTURE**


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(51) **Int. Cl.**

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| ***G06F 11/20*** | (2006.01) |
| ***G06F 11/30*** | (2006.01) |
| *G06F 11/14* | (2006.01) |
| *G06F 11/16* | (2006.01) |

(52) **U.S. Cl.**

CPC .......... ***G06F 11/2041*** (2013.01); ***G06F 11/008*** (2013.01); ***G06F 11/2035*** (2013.01); ***G06F 11/3051*** (2013.01); *G06F 11/1484* (2013.01); *G06F 11/1666* (2013.01); *G06F 11/20* (2013.01)

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USPC .............................................. 714/4.2, 3, 47.3

See application file for complete search history.


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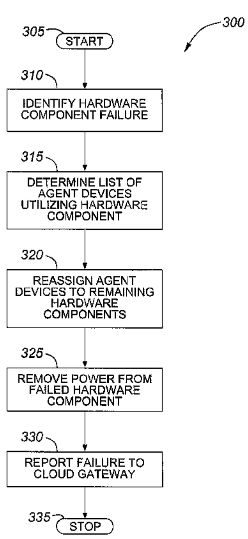
(57) **ABSTRACT**


Various exemplary embodiments relate to a method and related network node including one or more of the following: identifying a hardware failure of a failed component of a plurality of hardware components; determining a set of agent devices currently configured to utilize the failed component; reconfiguring an agent device to utilize a working component of the plurality of hardware components. Various exemplary embodiments additionally or alternatively relate to a method and related network node including one or more of the following: projecting a failure date for the hardware module; determining whether the projected failure date is acceptable based on a target replacement date for the hardware module; if the projected failure date is not acceptable: selecting a parameter adjustment for a hardware component, wherein the parameter adjustment is selected to move the projected failure date closer to the target replacement date, and applying the parameter adjustment to the hardware component.


**37 Claims, 9 Drawing Sheets**



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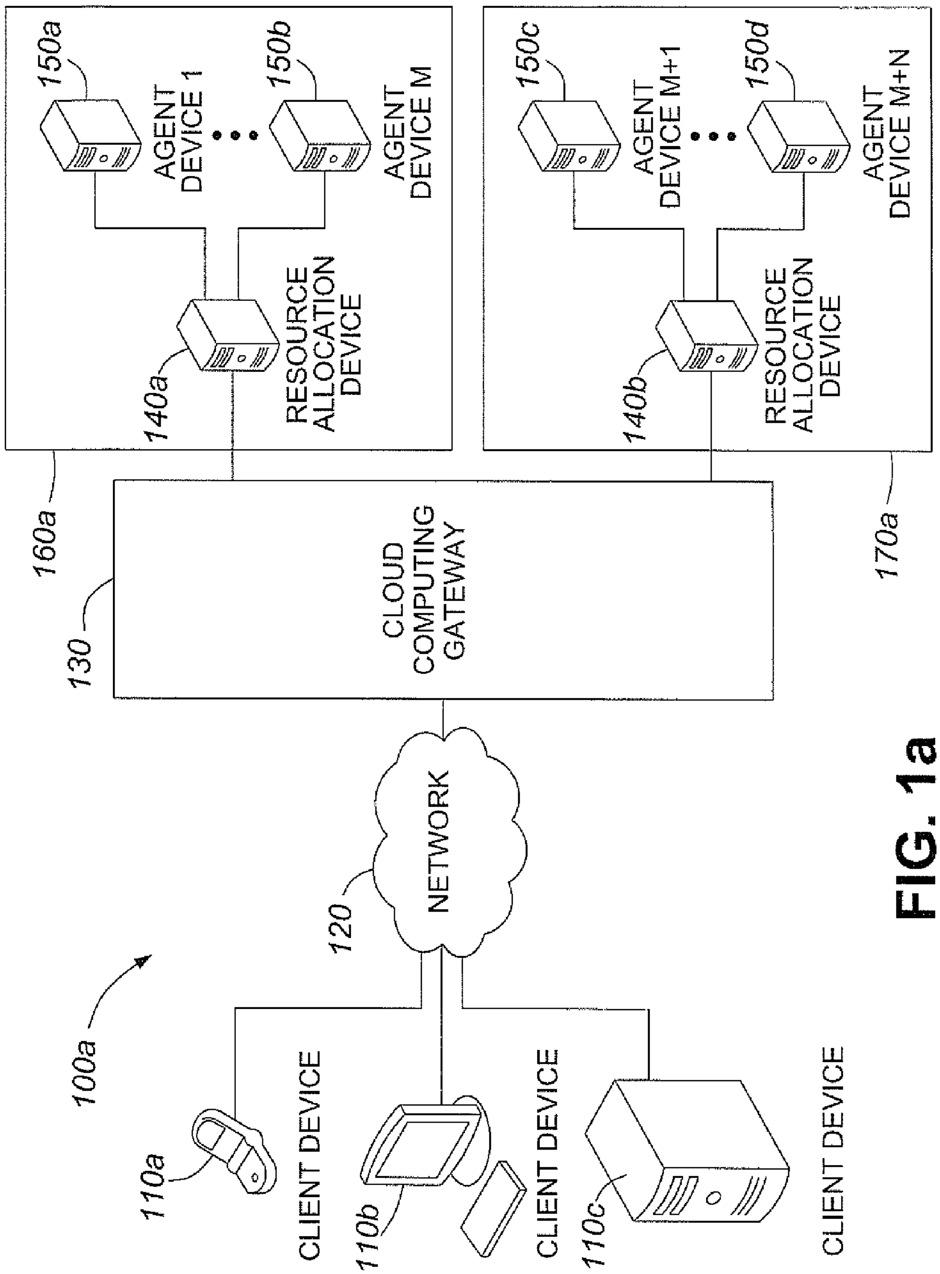

100a
110a
CLIENT DEVICE
110b
CLIENT DEVICE
110c
CLIENT DEVICE
120
NETWORK
130
CLOUD COMPUTING GATEWAY
160a
140a
RESOURCE ALLOCATION DEVICE
150a
AGENT DEVICE 1
150b
AGENT DEVICE M
170a
140b
RESOURCE ALLOCATION DEVICE
150c
AGENT DEVICE M+1
150d
AGENT DEVICE M+N

FIG. 1a

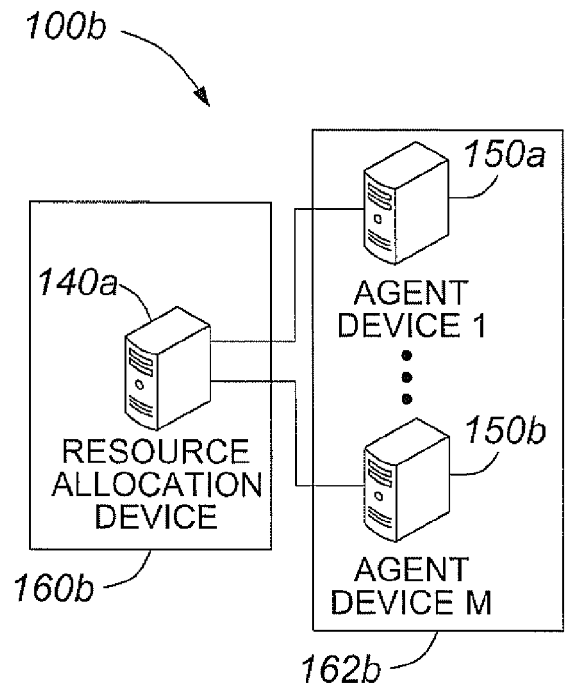

100b
150a
140a
AGENT
DEVICE 1
150b
RESOURCE
ALLOCATION
DEVICE
160b
AGENT
DEVICE M
162b

FIG. 1b

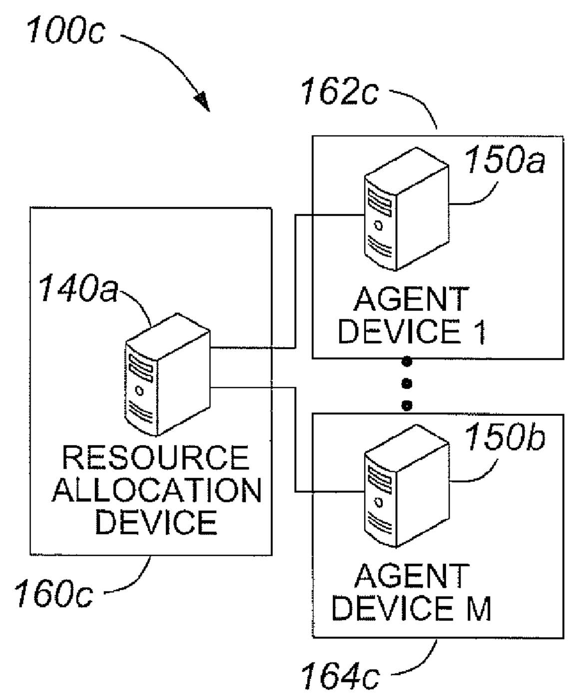
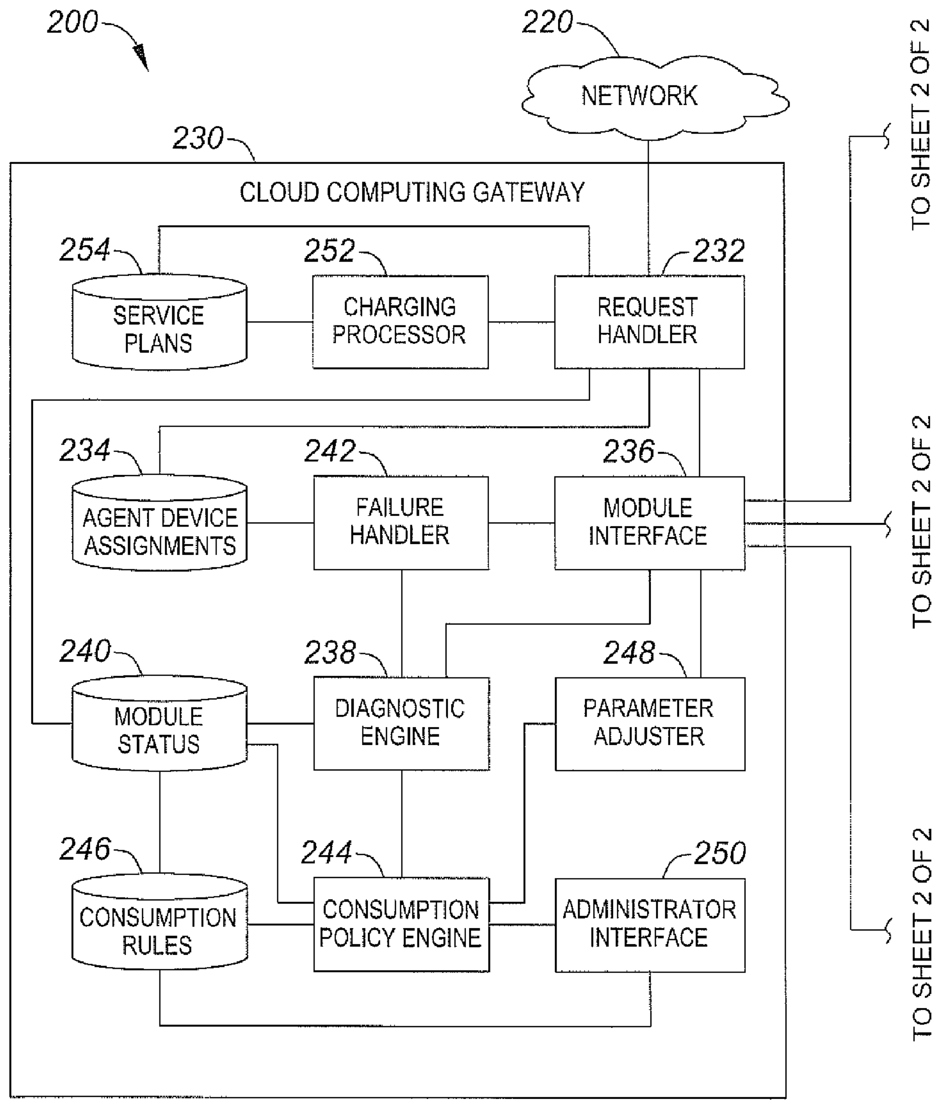
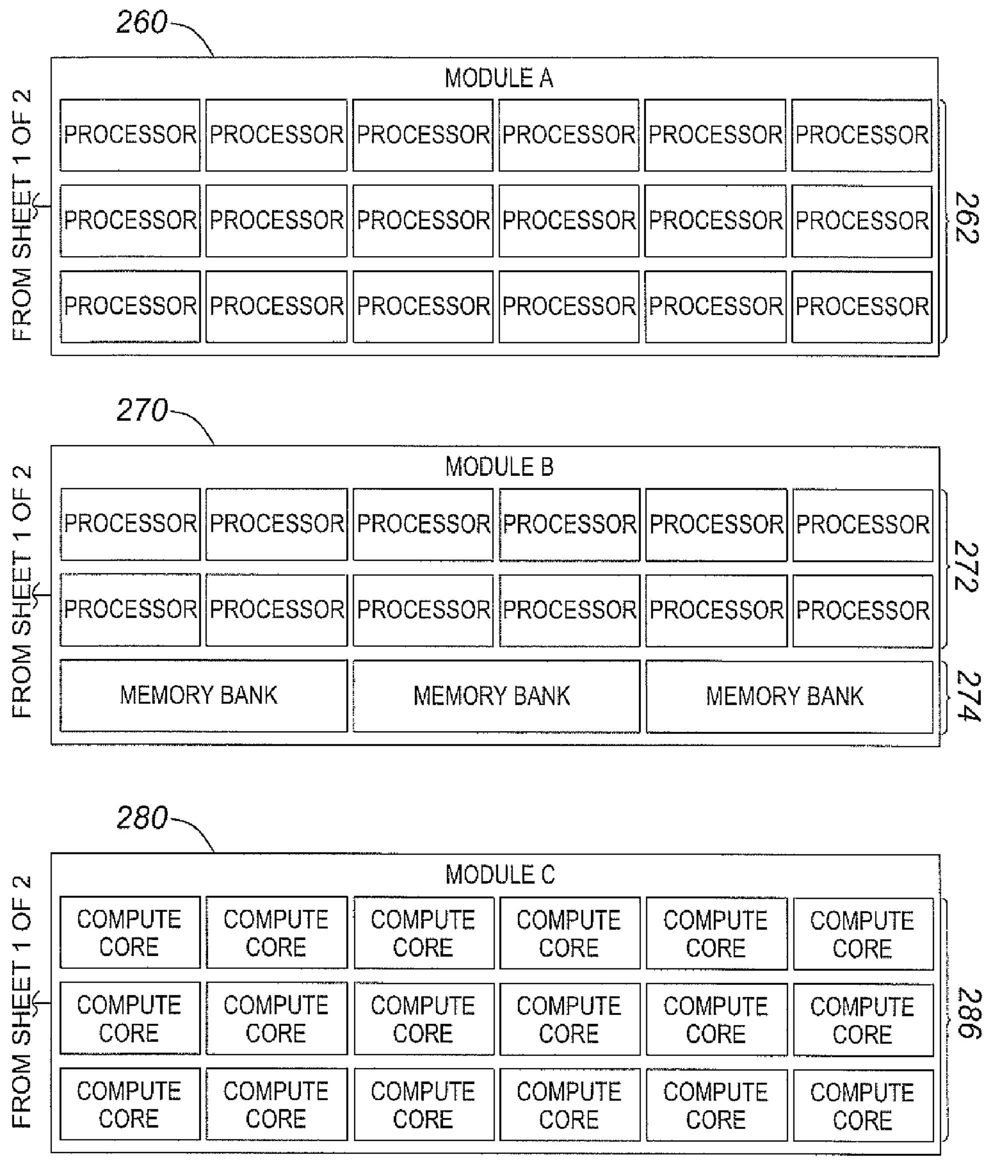

100c
162c
150a
140a
AGENT
DEVICE 1
150b
RESOURCE
ALLOCATION
DEVICE
160c
AGENT
DEVICE M
164c

FIG. 1c




(SHEET 1 OF 2)

FIG. 2




(SHEET 2 OF 2)

FIG. 2

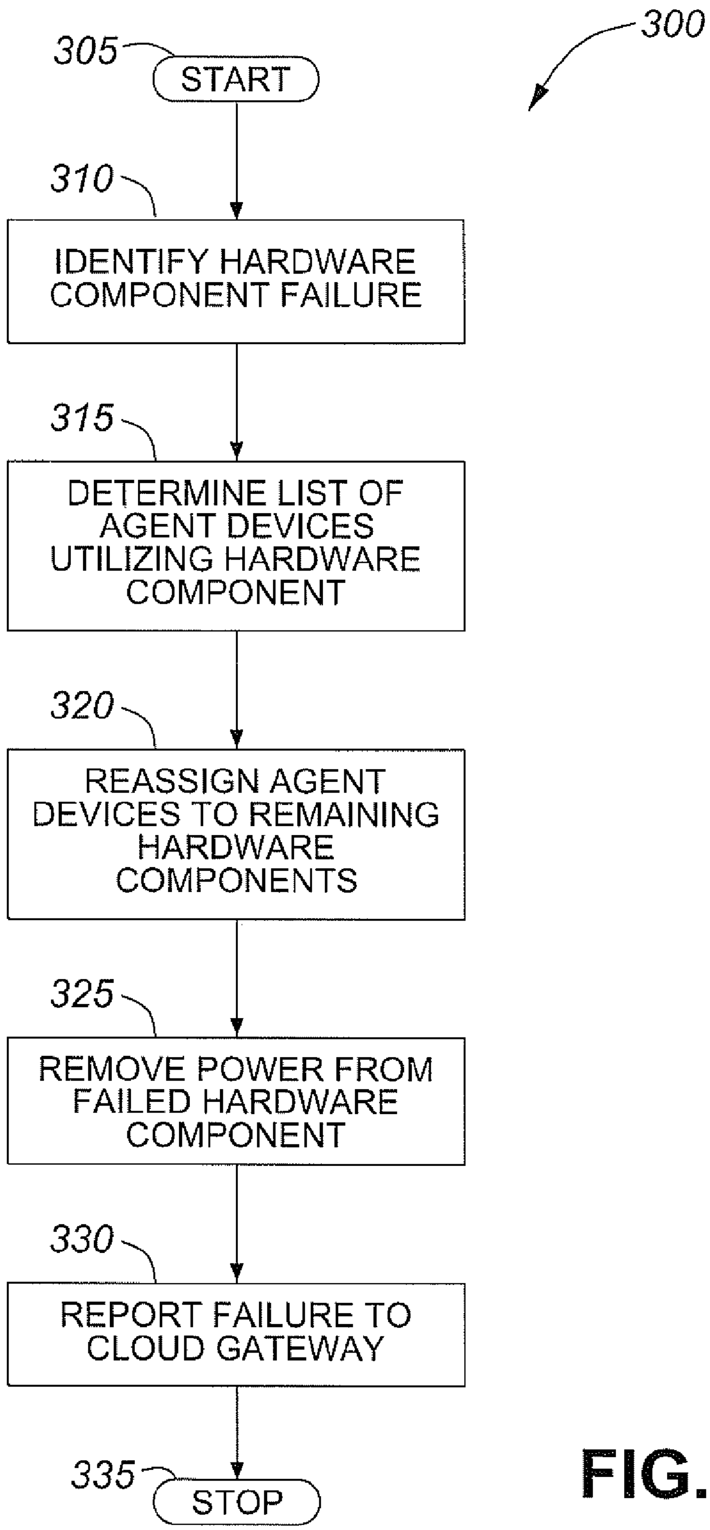

300
305
START
310
IDENTIFY HARDWARE COMPONENT FAILURE
315
DETERMINE LIST OF AGENT DEVICES UTILIZING HARDWARE COMPONENT
320
REASSIGN AGENT DEVICES TO REMAINING HARDWARE COMPONENTS
325
REMOVE POWER FROM FAILED HARDWARE COMPONENT
330
REPORT FAILURE TO CLOUD GATEWAY
335
STOP

FIG. 3

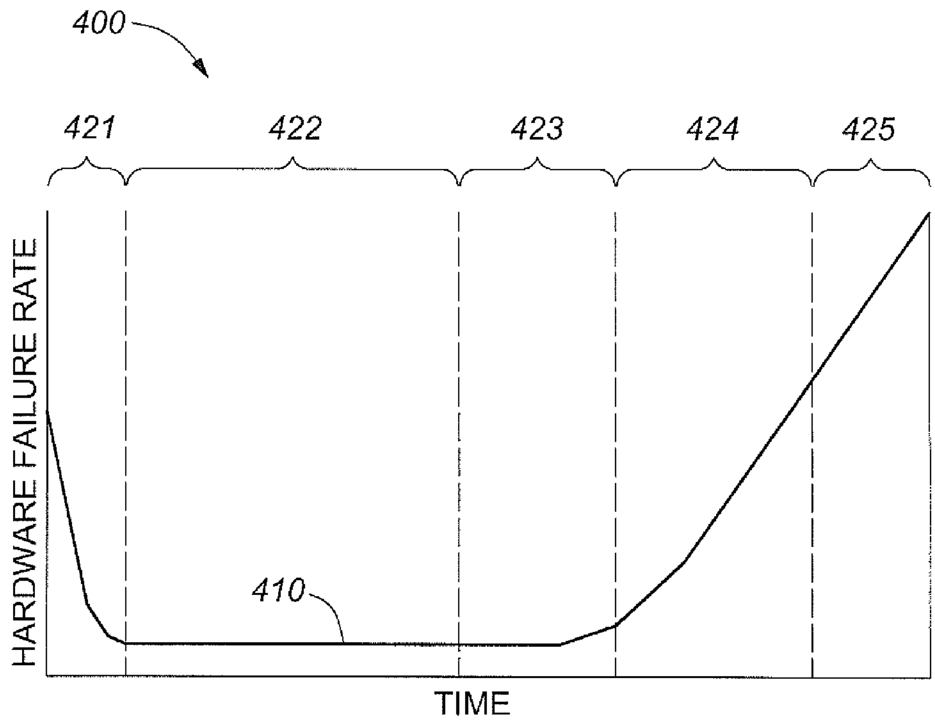



FIG. 4

500

| | MODULE (510) | LIFE PHASE (520) | COMPONENT (530) | FAILURE RATE (540) |
|---|---|---|---|---|
| 560 / 562 | A | 3 | CPU1 | 5% |
| 564 | | | CPU2 | 50% |
| 566 | | | . . . | . . . |
| 570 / 572 | B | 4 | CPU1 | 30% |
| 573 | | | . . . | . . . |
| 574 | | | MEM BANK1 | 10% |
| 576 | | | MEM BANK2 | 60% |
| 578 | | | . . . | . . . |
| 580 / 582 | C | 2 | COMPUTE CORE1 | 5% |
| 584 | | | COMPUTE CORE 2 | 5% |
| 586 | | | . . . | . . . |

FIG. 5

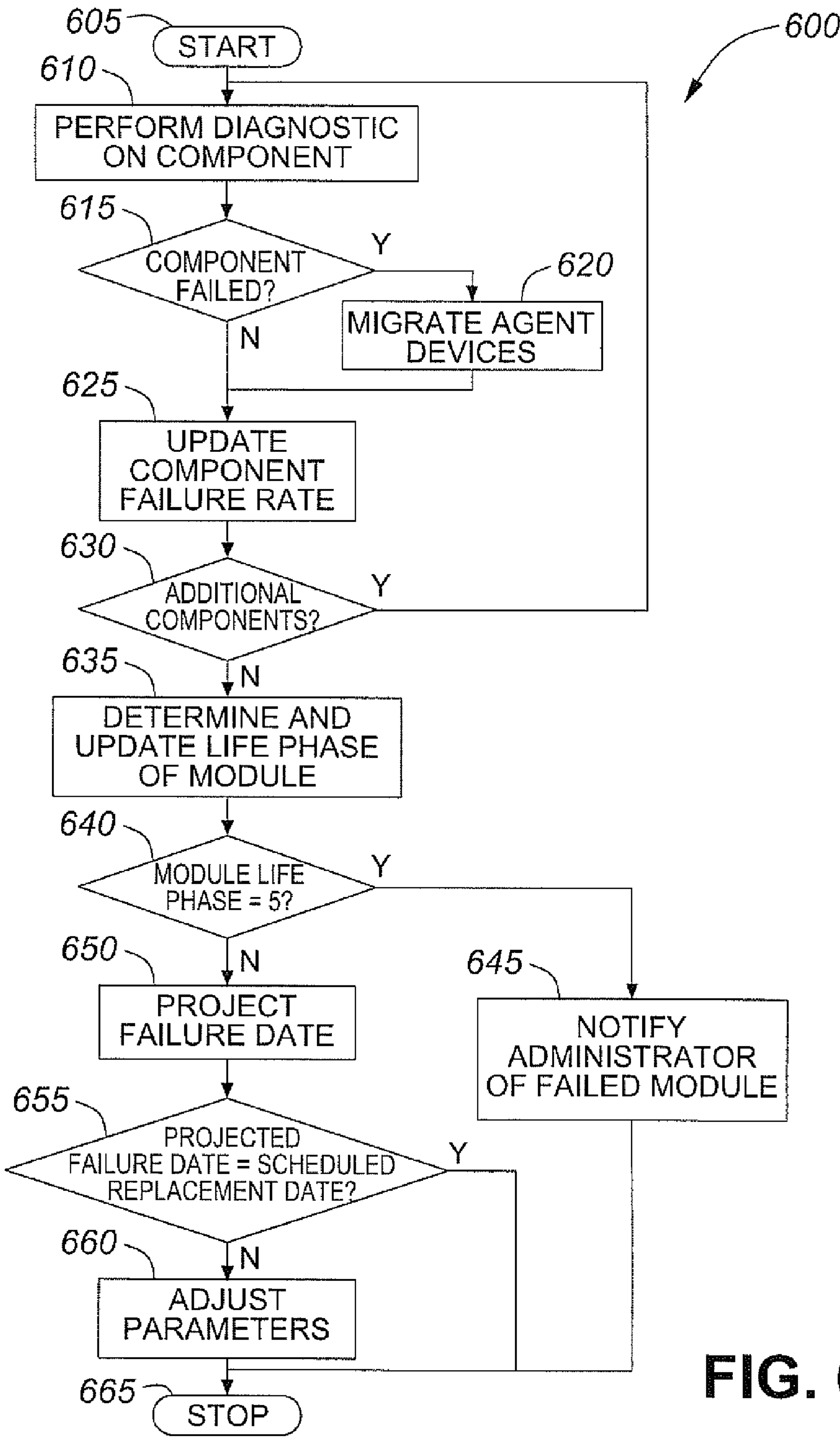
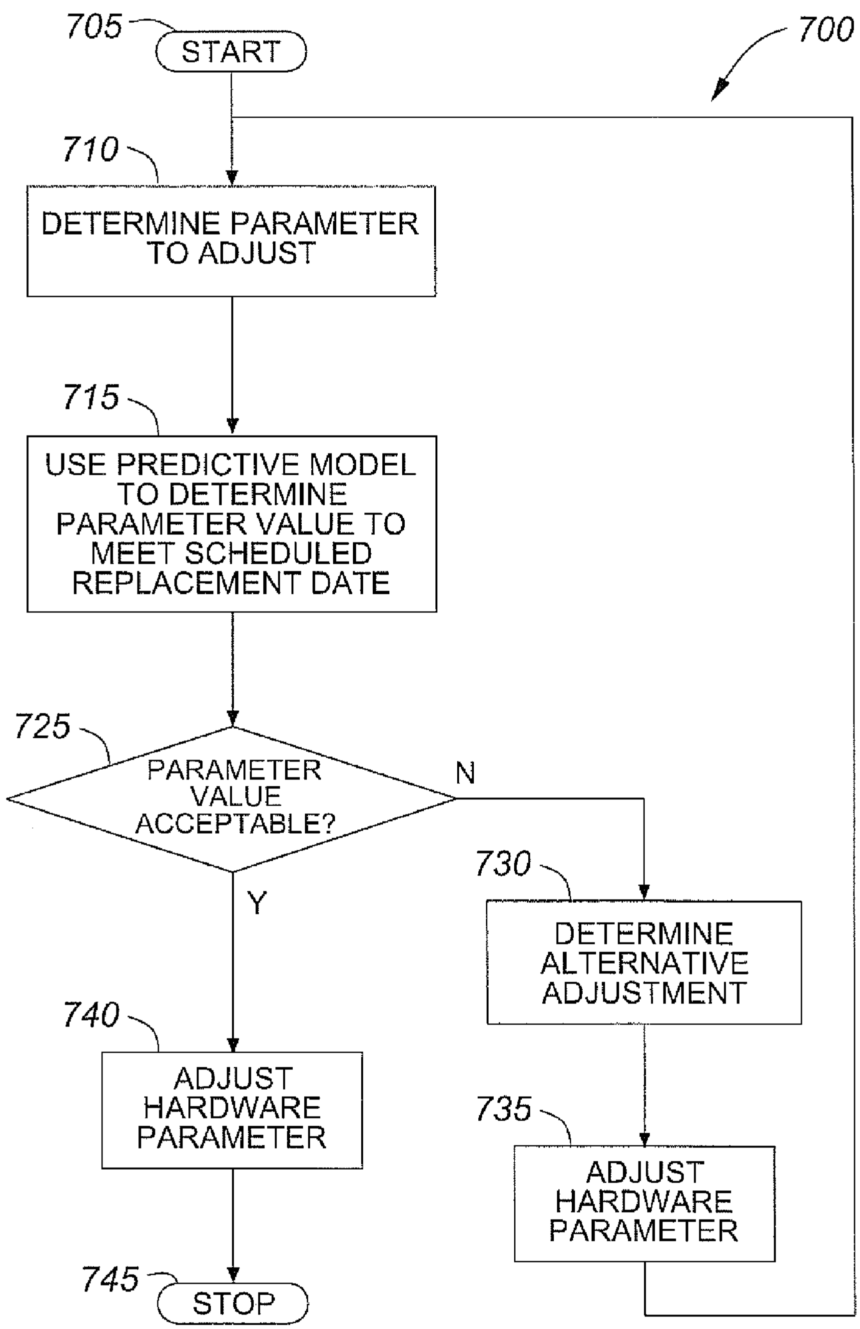

600
605
START
610
PERFORM DIAGNOSTIC ON COMPONENT
615
COMPONENT FAILED?
Y
620
MIGRATE AGENT DEVICES
N
625
UPDATE COMPONENT FAILURE RATE
630
ADDITIONAL COMPONENTS?
Y
635
N
DETERMINE AND UPDATE LIFE PHASE OF MODULE
640
MODULE LIFE PHASE = 5?
Y
650
N
PROJECT FAILURE DATE
645
NOTIFY ADMINISTRATOR OF FAILED MODULE
655
PROJECTED FAILURE DATE = SCHEDULED REPLACEMENT DATE?
Y
660
N
ADJUST PARAMETERS
665
STOP

FIG. 6



705
START
700
710
DETERMINE PARAMETER TO ADJUST
715
USE PREDICTIVE MODEL TO DETERMINE PARAMETER VALUE TO MEET SCHEDULED REPLACEMENT DATE
725
PARAMETER VALUE ACCEPTABLE?
N
Y
730
DETERMINE ALTERNATIVE ADJUSTMENT
740
ADJUST HARDWARE PARAMETER
735
ADJUST HARDWARE PARAMETER
745
STOP


FIG. 7

# HARDWARE CONSUMPTION ARCHITECTURE

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application cross-references the following co-pending application, incorporated by reference herein, in its entirety: application Ser. No. 13/250,333, "LIVE MODULE DIAGNOSTIC TESTING" to Bauer et al.

## TECHNICAL FIELD

Various exemplary embodiments disclosed herein relate generally to system reliability and availability.

## BACKGROUND

The rise of technologies such as virtualization and cloud computing has facilitated moving various applications previously associated with dedicated and standalone hardware onto machines providing shared hardware resources. This so-called "server consolidation" allows for a fuller utilization of available resources and, therefore, a decreased cost associated with underutilized resources. For example, energy consumption, floor space, and other server costs may be reduced by retiring servers that were previously only lightly utilized.

Server consolidation can lead to various unwanted effects, however. The increased utilization of hardware resources can increase the hardware's failure rate. These failures may then impact applications utilizing the hardware. Further, under current architectures, when a hardware component of a field replaceable unit (FRU), such as a blade or rack mount server fails, the, unit often must be replaced or repaired, removing the resources associated with the unit from the pool of resources available for application execution, even though most hardware components of the server may remain operational.

## SUMMARY

A brief summary of various exemplary embodiments is presented below. Some simplifications and omissions may be made in the following summary, which is intended to highlight and introduce some aspects of the various exemplary embodiments, but not to limit the scope of the invention. Detailed descriptions of a preferred exemplary embodiment adequate to allow those of ordinary skill in the art to make and use the inventive concepts will follow in later sections.

Various exemplary embodiments relate to a method performed by a hardware management device for enabling incremental failure of a hardware system, the hardware system including a plurality of hardware components, the method including one or more of the following: identifying a hardware failure of a failed component of the plurality of hardware components; determining set of agent devices currently configured to utilize the failed component; and for at least one agent device of the set of agent devices, reconfiguring the agent device to utilize a working component of the plurality of hardware components in place of the failed component; and deactivating the failed component, wherein other hardware components of the plurality of hardware components remain in operation.

Various exemplary embodiments relate to a hardware system capable of incremental hardware failure, the hardware system including: a circuit board; a plurality of hardware components mounted on the circuit board; and a management device that, during run time, deactivates at least one hardware component of the plurality of hardware components while at least one remaining component of the plurality of hardware components remains in operation.

Various exemplary embodiments relate to a tangible and non-transitory machine-readable storage medium encoded with instructions for execution by a hardware management device for enabling incremental failure of a hardware system, the hardware system including a plurality of hardware components, the tangible and non-transitory machine-readable storage medium including one or more of the following: instructions for identifying a hardware failure of a failed component of the plurality of hardware components; instructions for determining set of agent devices currently configured to utilize the failed component; and instructions for, for at least one agent device of the set of agent devices, reconfiguring the agent device to utilize a working component of the plurality of hardware components in place of the failed component; and instructions for deactivating the failed component, wherein other hardware components of the plurality of hardware components remain in operation.

Various exemplary embodiments additionally include reconfiguring the hardware module to power down the failed component while continuing to provide power to at least one other component of the plurality of hardware components.

Various exemplary embodiments are described wherein the hardware system is a hardware module including a circuit board upon which the plurality of hardware components is mounted.

Various exemplary embodiments are described wherein all hardware components mounted on the circuit board are of a single type of hardware component.

Various exemplary embodiments are described wherein the hardware management device includes a hypervisor and wherein the hardware management device utilizes at least one component of the plurality of hardware components to operate.

Various exemplary embodiments are described wherein the hardware management device includes a cloud computing gateway device and wherein: the cloud management device manages a plurality of hypervisors; and a first hypervisor of the plurality of hypervisors manages the plurality of hardware components.

Various exemplary embodiments additionally include, for at least one agent device of the set of agent devices, reconfiguring the agent device to be managed by a second hypervisor of the plurality of hypervisors.

Various exemplary embodiments relate to a method performed by a hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the method including one or more of the following: projecting a failure date for the hardware module; determining whether the projected failure date is acceptable based on a target replacement date for the hardware module; if the projected failure date is not acceptable: determining at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and applying the at least one parameter adjustment to the at least one hardware component of the plurality of hardware components.

Various exemplary embodiments relate to a hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the hardware management device including one or more of the following: a consumption policy

engine configured to: project a failure date for the hardware module, and determine whether the projected failure date is acceptable based on a target replacement date for the hardware module; and a parameter adjuster that is configured to, if the projected failure date is not acceptable: determine at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and apply the at least one parameter adjustment to the at least one hardware component of the plurality of hardware components.

Various exemplary embodiments relate to a tangible and non-transitory machine-readable storage medium encoded with instructions for execution by a hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the tangible and non-transitory machine-readable storage medium including one or more of the following: instructions for projecting a failure date for the hardware module; instructions for determining whether the projected failure date is acceptable based on a target replacement date for the hardware module; instructions for, if the projected failure date is not acceptable: determining at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and applying the at least one parameter adjustment to the at least one hardware component of the plurality of hardware components.

Various exemplary embodiments are described wherein the at least one parameter adjustment is selected to cause the hardware module to fail sooner than the projected failure date.

Various exemplary embodiments additionally include estimating a current life phase for the module based on a failure rate for each of the plurality of hardware components; wherein the step of projecting a failure date for the hardware module is performed based on the current life phase of the module.

Various exemplary embodiments are described wherein the hardware management device manages a plurality of hardware modules and each hardware module is associated with a current life phase, and further including one or more of the following: receiving a request for establishment of an agent device; determining a life phase permission associated with the request, wherein the life phase permission indicates that a module having a permitted life phase should be used for fulfilling the request; selecting a hardware module of the plurality of hardware modules, wherein the selected hardware module is associated with the permitted life phase; and fulfilling the request using the selected hardware module.

Various exemplary embodiments are described wherein the step of projecting a failure date for the hardware module includes projecting a date at which a failure condition will be met, wherein the failure condition is met when less than a configured number of hardware components remain operational.

Various exemplary embodiments additionally include determining a failure rate of at least one of the plurality of hardware components, wherein the step of projecting a failure date for the hardware module is performed based on the failure rate of at least one of the plurality of hardware components.

Various exemplary embodiments are described wherein the at least one parameter adjustment includes an adjustment to at least one of the following: a cooling rate, a voltage, a clock frequency, and an activation schedule.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand various exemplary embodiments, reference is made to the accompanying drawings, wherein:

FIG. **1***a* illustrates an exemplary system for providing shared hardware resources;

FIG. **1***b* illustrates an alternative arrangement for some components of FIG. **1***a;*

FIG. **1***c* illustrates another alternative arrangement for some components of FIG. **1***a;*

FIG. **2** illustrates an exemplary hardware system from providing consumable hardware resources;

FIG. **3** illustrates an exemplary method for handling a failed hardware component;

FIG. **4** illustrates an exemplary graph of the failure rate of a hardware module over time;

FIG. **5** illustrates an exemplary data arrangement for storing hardware status information;

FIG. **6** illustrates an exemplary method for controlling the consumption of hardware resources; and

FIG. **7** illustrates an exemplary method for adjusting hardware parameters.

To facilitate understanding, identical reference numerals have been used to designate elements having substantially the same or similar structure and/or substantially the same or similar function.

## DETAILED DESCRIPTION

In view of the foregoing, it would be desirable to provide a hardware architecture that limits the impact of a failed hardware resource on the total resources available. In particular, it would be desirable for such an architecture to deactivate any failed components while all other components remain fully operational. Referring now to the drawings, there are disclosed broad aspects of various exemplary embodiments.

FIG. **1***a* illustrates an exemplary system **100***a* for providing shared hardware resources. Such hardware resources may be shared, for example, to support some networked application serving client users. Exemplary system may include a number of client devices **110***a-c*, a network **120**, cloud computing gateway **130**, resource allocation devices **140***a-b*, and a number of agent devices **150***a-d*. Resource allocation devices **140***a-b* and agent devices **150***a-d* may reside among one or more cloud computing infrastructure.

Client devices **110** *a-c* may each include any device capable of communicating with a network such as network **120**. While three devices are illustrated here, exemplary system **100***a* may include fewer or more devices. Further, the number of client devices participating in exemplary system **100***a* may change during operation. For example, client device **110***a* may cease participating in exemplary system **100***a* and/or another two client devices (not shown) may commence similar participation.

Each client device **110***a-c* may be a personal or laptop computer, terminal, server, tablet, wireless email device, cell phone, smart phone, television set-top box, or any other device capable of communicating with other devices via network **120**. Each client device **110***a-c* may participate in exemplary system **100***a* for different reasons. For example, client device **110***a* may be a thin client and may rely on other resources within exemplary system **100***a* to perform most or all processing related to the normal operation of client device

**110***a*. As another example, client device **110***b* may be a personal computer capable of independently performing most tasks and may rely on other resources within exemplary system **100***a* to store and retrieve data such as, for example, a large music or eBook collection. As yet another example, client device **110***c* may be a server that receives and responds to requests from other devices (not shown). Client device **110***c* may rely on other resources within exemplary system **100***a* to process a portion of such requests when the rate at which such requests arrive is too high for client device **110***c* to process within some measure of efficiency, response time, or other metric for gauging server load.

Network **120** may be a device or group of devices adapted to provide communication between other devices of exemplary system **100***a*. Accordingly, network **120** may include a number of routers and/or switches for forwarding packets to appropriate destinations. In various embodiments, network **120** may include one or more 2G, 3G, and/or 4G systems and/or other wireless systems. Further, in various embodiments, network **120** may include wired networks such as the Internet and/or one or more local area networks (LANs).

Cloud computing gateway **130** may be a device or group of devices adapted to manage hardware resources. As such, cloud computing gateway may effect the establishment of agent devices such as agent devices **150***a-d*, route messages between client devices **110***a-c* and agent devices **150***a-d*, charge users for hardware utilization, monitor the state of hardware resources, and/or control consumption of hardware resources. The detailed operation of cloud computing gateway will be described in greater detail below with respect to FIG. **2**.

As will be described in greater detail below, the hardware resources managed by cloud computing gateway **130** may include a number of hardware modules. Each hardware module may be a circuit board that includes a number of hardware components. The hardware components, in turn, provide the hardware resources managed by the cloud computing gateway **130**. For example, one hardware module may be a circuit board on which thirty-two processors are mounted. The cloud computing gateway **130** may operate to manage, at least in part, the usage and consumption of the processing capacity of those thirty-two processors. Further examples of hardware modules will be described with reference to FIG. **2**. Exemplary system **100***a*, as illustrated, may include two hardware modules **160***a*, **170***a*. Note that while two hardware modules **160***a*, **170***a* are illustrated, exemplary system **100***a* may include fewer or more hardware modules (not shown).

Resource allocation devices **140***a-b* may each be a device that utilizes hardware resources of a hardware module such as hardware modules **160***a*, **170***a*. Resource allocation devices **140***a-b* may also manage agent devices **150***a-d*. For example, resource allocation device **140***a* may manage agent devices **150***a-b*, while resource allocation device **140***b* may manage agent devices **150***c-d*. In managing agent devices **150***a-d*, resource allocation devices **140***a-b* may assign and/or enforce shared hardware resources of hardware modules **160***a*, **170***a* with respect to each agent device **140***a-d*. For example, resource allocation device **140***a* may ensure that agent device **1 150***a* may use 20% of the processing time on a first CPU while agent device M **150***b* may use 10% of the processing time on the same CPU. Accordingly, in various embodiments, resource allocation devices **140***a-b* may each include a hypervisor. Resource allocation devices **140***a-b* may perform numerous additional functions such as, for example, request and response message routing, resource reservation, load balancing, usage metering, and/or charging. Note that while exemplary system **100***a* includes two resource allocation devices **140***a-b*, various embodiments may include fewer or more resource allocation devices (not shown).

Agent devices **150***a-d* may each be devices configured to operate in conjunction with one or more of client devices **110***a-c*. Each agent device **150***a-d* may include hardware resources such as one or more processors, memory, storage, and/or network interfaces. In various embodiments, agent devices **150***a-d* may share such hardware resources with other agent devices **150***a-d* and/or resource allocation devices **140***a-b*. For example, agent device **1 150***a* may share a CPU with resource allocation device **140***a* and agent device M **150***b*. Such hardware resources may be disposed among one or more physical hardware modules such as hardware modules **160***a*, **170***a*. In various embodiments, one or more of agent devices **150***a-d* may include a virtual machine.

According to some embodiments, resource allocation devices **140***a-b* may reside together on the same physical hardware modules as the agent devices **150***a-d* that they manage. For example, resource allocation device **140***a* and agent devices **150***a-b* may reside together on a single physical hardware module **160***a*. In such embodiments, resource allocation device **140***a* may include a hypervisor while agent devices **150***a-b* may each include a virtual device, all of which may execute using various hardware components of the same hardware module. Likewise, resource allocation device **140***b* and agent devices **150***c-d* may reside together on another physical hardware module **170***a*. It should be apparent, however, that the methods described herein may be applied to various alternative configurations. For example, alternative configuration **100***b* as illustrated in FIG. **1***b*, shows that resource allocation device **140***a* may reside on a first hardware module **160***b* while agent devices **150***a-b* may all reside on a second hardware module **162***b*. As another alternative, alternative configuration **100***e* as illustrated in FIG. **1***c* shows that resource allocation device **140***a* and agent devices **150***a-b* may each reside on an independent hardware module **160***c*, **162***c*, **164***c*, respectively. Further, each resource allocation device **140***a* and agent devices **150***a-b* may utilize resources provided by multiple hardware modules. Various additional arrangements may be apparent to those of skill in the art.

Returning to FIG. **1***a*, cloud computing gateway **130** and/or resource allocation devices **140***a-b* may be configured to handle failures of the hardware components of a hardware module. For example, if a CPU of hardware module **160***a* fails or is otherwise deemed unusable, cloud computing gateway **130** and/or resource allocation device **140***a* may deactivate the failed CPU by modifying software or hardware configurations of the CPU or otherwise removing the CPU from the available resource pool. Cloud computing gateway **130** and/or resource allocation device **140***a* may subsequently reduce operational expenses as well by reconfiguring hardware module **160***a* to power down the failed CPU. Cloud computing gateway **130** and/or resource allocation device **140***a* may further reconfigure any agent devices **150***a-b* previously using the failed CPU to instead utilize a different CPU on module **160***a* or a CPU on another module such as module **170***a*. In this way, the hardware modules **160***a*, **170***a* may remain operational as their constituent components fail. The modules may continue to function, albeit at diminished capacity, as they incrementally fail. When the module capacity falls below a point where it is cost-effective to continue operation, the hardware module may be discarded and replaced. In this manner, the present architecture provides for the consumption of hardware resources.

Cloud computing gateway **130** and/or resource allocation devices **140***a-b* may further be adapted to manage the consumption of hardware modules **160**_a_, **170**_a_. In particular, cloud computing gateway **130** and/or resource allocation devices **140**_a-b_ may adjust various operating parameters of hardware modules **160**_a_, **170**_a_, or the components thereof, to ensure that the hardware module **160**_a_, **170**_a_ reach the end of their useful lives at or slightly beyond a target replacement date. If, for example, hardware module **160**_a_ is predicted to become non-cost-effective sooner than its target replacement date, cloud computing gateway **130** and/or resource allocation device **140**_a_ may adjust the operating parameters to prolong the life of the hardware module such as, for example, lowering an operating voltage or clock rate to reduce component stress and thereby prolong its useful service life. Conversely, if hardware module **170**_a_ is predicted to remain cost effective for some time after its target replacement date, cloud computing gateway **130** and/or resource allocation device **140**_b_ may adjust the operating parameters to shorten the life of the hardware module, such as, for example boosting workload, thereby ensuring maximum usage of the hardware module by the time it is replaced, or lowering a cooling rate, thereby reducing operational expenses.

System administrators may use the above functionality to plan for periodic replacement of all hardware modules. For example, system administrators may configure each hardware module to have a useful life of three years, staggered such that each month 1/36 of the total hardware modules are to be replaced. In a system employing the methods described herein, the system administrator is assured that when a hardware module is replaced on the scheduled date, it has been fully utilized and is truly no longer cost effective to keep in operation.

FIG. **2** illustrates an exemplary hardware system **200** from providing consumable hardware resources. Exemplary hardware system **200** may correspond to a portion of exemplary system **100**_a_. Exemplary hardware system **200** may include network **220**, cloud computing gateway **230**, and hardware modules **260**, **270**, **280**.

Network **220** may be a device or group of devices adapted to provide communication between other devices of exemplary system **100**_a_. Accordingly, network **120** may include a number of routers and/or switches for forwarding packets to appropriate destinations. In various embodiments, network **120** may include one or more 2G, 3G, and/or 4G systems and/or other wireless systems. Further, in various embodiments, network **120** may include wired networks such as the Internet and/or one or more local area networks (LANs). In various embodiments, network **220** may correspond to network **120** of exemplary system **100**_a_.

Cloud computing gateway **230** may be a device or group of devices adapted to manage hardware resources. Accordingly, cloud computing gateway **230** may correspond to cloud computing gateway **130** of exemplary system **100**_a_. Cloud computing gateway **230** may include request handler **232**, agent device assignments storage **234**, module interface **236**, diagnostic engine **238**, module status storage **240**, failure handler **242**, consumption policy engine **244**, consumption rules storage **246**, parameter adjuster **248**, administrator interface **250**, charging processor **252**, and service plans storage **254**. It should be noted that various components of cloud computing gateway **230** may alternatively or additionally be located at one or more resource allocation devices (not shown) resident on one or more hardware modules **260**, **270**, **280**.

Request handler **232** may include hardware and/or executable instructions on a machine-readable storage medium configured to receive and process requests for agent devices. For example, request handler **232** may receive a request from a client device (not shown) via network **220** requesting the establishment of a new agent device. Subsequently, request handler may determine an appropriate module **260**, **270**, **280** to host the new agent device and then communicate via module interface **236** with a resource allocation device (not shown) resident on the module **260**, **270**, **280** to effect establishment of the new agent device. The selection of the appropriate module **260**, **270**, **280** may be based, at least in part, on the current condition of the module **260**, **270**, **280** as stored in module status storage **240**, a service plan of the requesting user as stored in service plans storage **254**, and/or a reliability requirement for the application to be run on the new agent device. In establishing the new agent device, request handler **232** may also update the contents of agent device assignment storage to reflect the correspondence between the requesting client device, agent device, and hardware module(s) assigned to the agent device.

Request handler **232** may perform additional functionality such as routing messages between client devices (not shown) and active agent devices (not shown). To effect such functionality, request handler **232** may refer to data stored in agent device assignments storage **234** to determine which resource allocation device and/or hardware modules are associated with which client device. Request handler **232** may also forward data regarding establishment and usage of agent devices to charging processor such that a user of each client device (not shown) can be billed appropriately.

Agent device assignments storage **234** may be any machine-readable medium capable of storing information descriptive of agent devices. Accordingly, agent device assignments storage **234** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media. In various embodiments, agent device assignments storage **234** may store a correlation between each agent device and its associated resource allocation device and/or hardware module(s).

Module interface **236** may be an interface including hardware and/or executable instructions encoded on a machine-readable storage medium configured to enable communication with one or more hardware modules **260**, **270**, **280**. In various embodiments, module interface **236** may include an Ethernet, PCI, SCSI, ATA, and/or other hardware interface technologies. In various embodiments, module interface **236** may include a blade server backplane.

Diagnostic engine **238** may include hardware and/or executable instructions on a machine-readable storage medium configured to effect performance of various diagnostics on hardware modules **260**, **270**, **280** and the hardware components **262**, **272**, **274**, **286** thereof to gauge the current health and/or failure rate of those hardware devices. In various embodiments, diagnostic engine **238** may periodically initiate testing of each hardware component **262**, **272**, **274**, **286** to determine a current and/or historical failure rate of the hardware component **262**, **272**, **274**, **286**. For example, diagnostic engine may communicate with a resource allocation device resident on the appropriate hardware module **260**, **270**, **280** to remove the component from the resource pool and/or establish a new agent device for performance of one or more diagnostic tests. Diagnostic engine **238** may then receive test results via module interface **236** and subsequently update module status storage **240** to reflect the current status of the tested hardware component. If a test indicates that a hardware component has failed or is otherwise unusable, diagnostic engine may then send an instruction to failure handler **242** to take appropriate adaptive action, as will be described in further detail below.

Diagnostic engine **238** may further utilize the diagnostic results of the individual hardware components **262**, **272**, **274**, **286** as well as various "useful life" techniques, as are known in the art, to gauge a current life stage of the hardware module **260**, **270**, **280** as a whole. As will be described in greater detail below with respect to FIG. **4**, hardware components can be expected to exhibit different rates of failure at different stages in their useful life. This phenomenon often follows the well-known "bathtub curve" model. Diagnostic engine **238** may be adapted to determine a current life stage for each module **260**, **270**, **280** for the purposes of tiered service plans and failure projections.

Module status storage **240** may be any machine-readable medium capable of storing status information related to hardware modules and hardware components. Accordingly, module status storage **240** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media. Exemplary contents of module status storage **240** will be described in greater detail below with respect to FIG. **5**. In various embodiments, module status storage **240** may be the same device as agent device assignments storage **234**.

Failure handler **242** may include hardware and/or executable instructions on a machine-readable storage medium configured to react to various hardware components **262**, **272**, **274**, **286** failing or becoming otherwise unusable. Failure handler **242** may receive an indication of such a failure from diagnostic engine **238** and/or directly from a resource allocation device (not shown) operating on the corresponding hardware module **260**, **270**, **280**. In response to an indication that a hardware component is newly unusable, failure handler **242** may refer to agent device assignments storage **234** to determine which agent devices may have utilized the hardware component. Failure handler **234** may also determine whether the associated hardware module's reduced capacity is sufficient to continue supporting all of the agent devices to which the module is currently assigned. Based on this information, failure handler **242** may redistribute one or more agent devices to other hardware modules. For example, if a processor **262** on module A becomes unusable, failure handler **242** may communicate with the resource allocation devices on modules **260**, **270** to effect the movement of one or more agent devices to module B **270** to ensure that the performances of agent devices utilizing module A **260** do not suffer due to the module's now decreased capacity. Failure handler **242** may also update the contents of agent device assignments storage **234** to reflect the redistributed agent devices.

Consumption policy engine **244** may include hardware and/or executable instructions on a machine-readable storage medium configured to determine what action to take in response to the projected remaining life of a module. In various embodiments, using the status information stored in module status storage **240**, consumption policy engine **244** may project an estimated failure date for each hardware module **260**, **270**, **280** using various techniques known in the art. In various embodiments, rather than projecting a date of total failure for each module, consumption rules storage may store a failure condition for one or more modules **260**, **270**, **280**. This failure condition may specify a module status at which it is no longer cost effective to continue operating the module. For example, an administrator may determine that it is only cost effective to continue operating module A **260** while at least eight processors remain functional. Accordingly, consumption policy engine may project a date when module A **260** is expected to have less than eight functional processors.

Consumption policy engine **244** may then compare the projected failure date to a target replacement date for the module. Such target replacement date may be stored in consumption rules storage **246**. If the projected failure date is not sufficiently close to the target replacement date, consumption policy engine **244** may indicate this fact to parameter adjuster such that the consumption rate of the module may be altered. In various embodiments, consumption policy engine **244** may require that the projected failure date coincide with the target replacement date, while other embodiments may allow for a tolerance of a number of days or months. Such other embodiments may allow this tolerance beyond, but not before, the target replacement date.

Consumption rules storage **246** may be any machine-readable medium capable of storing status information related to when each hardware module should and will be replaced. Accordingly, consumption rules storage **246** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media. In various embodiments, consumption rules storage **246** may store a failure condition and target replacement date for each module. In various embodiments, consumption rules storage **246** may be the same device as agent device assignments storage **234** and/or module status storage **240**.

Parameter adjuster **248** may include hardware and/or executable instructions on a machine-readable storage medium configured to adjust various operating parameters of hardware components to shorten or prolong the useful life of hardware modules. Based on the target replacement date of a module and the projected failure date of the module, as reported by the consumption policy engine, the parameter adjuster may utilize one or more predictive models to determine one or more parameter adjustments operable to move the projected failure date of the module closer to the target replacement date. Such predictive models may be provided by, for example, hardware manufacturers of the hardware components **262**, **272**, **274**, **286** and/or hardware modules **260**, **270**, **280**. For example, if parameter adjuster **260** receives an indication that module A **260** is scheduled to be replaced in October, but has a projected life extending through November, parameter adjuster **248** may determine that the useful life of module A should be shortened by one month. Using manufacturer-provided predictive models, parameter adjuster **248** may determine that overclocking processors **262** by an additional 200 MHz would reduce the useful life of module A **260** by about a month. After determining an appropriate parameter adjustment, parameter adjuster **248** may further be adapted to communicate with the hardware module **260**, **270**, **280** via module interface **236** to effect the parameter adjustment on the hardware.

Administrator interface **250** may include various devices such as a display, keyboard, and/or mouse such that an administrator may interact with the cloud computing gateway **230**. In various embodiments, when the diagnostic engine **238**, consumption policy engine **244**, or other component determines that a module **260**, **270**, **280** has failed and must be replaced, possibly before the target replacement date, administrator interface may alert the administrator to the failure. Further administrator interface **250** may enable the administrator to modify the contents of consumption rules storage **246**. For example, the administrator may be able to use administrator interface **250** to define failure conditions and target replacement dates for various modules **260**, **270**, **280**. For example, the administrator may modify the failure condition of module A from less than 6 operational processors to less than 8 operational processors in view of an updated business decision. Various additional uses for administrator interface **250** will be apparent to those of skill in the art.

Charging processor **252** may include hardware and/or executable instructions on a machine-readable storage medium configured to charge users of exemplary hardware system. Charging processor **252** may receive indications of activity from request handler **232** and subsequently charge an account of the associated user based on their service plan. Various metering and charging methods will be apparent to those of skill in the art.

Service plans storage **254** may be any machine-readable medium capable of storing information regarding service plans associated with various users of exemplary hardware system **200**. Accordingly, service plans storage **254** may include a machine-readable storage medium such as read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and/or similar storage media. In various embodiments, service plans storage **254** may store user identification data, billing information, service tiers, and other information useful in defining the privileges and charging details for various users. In various embodiments, service plans storage **254** may be the same device as agent device assignments storage **234**, module status storage **240**, and/or consumption rules storage **246**.

Hardware modules **260**, **270**, **280** may each be a hardware module that provides hardware resources for use in exemplary hardware system **200**. Hardware modules **260**, **270**, **280** illustrate three different possible configurations of hardware modules. Those of skill in the art will understand that while three possibilities are illustrated, various alternative configurations may also exist. Further, while three hardware modules **260**, **270**, **280** are shown, hardware system **200** may include fewer or more hardware modules.

Hardware module A **260** may be a homogenous type hardware module. In other words, module A **260** may include hardware components of a single type. In the illustrated example, module A **260** includes eighteen processors **262** and no other hardware components. It should be noted that, as used herein, the term "hardware component" refers to those components providing hardware resources to be used as part of a resource allocation device or agent device, or otherwise to be offered for use by an external client device. Accordingly, while module A **260** may include additional hardware such as, for example, a power supply and/or a communication interface to support processors **262**, such hardware does not constitute hardware components.

One or more of processors **262** may belong, at least in part, to a resource allocation device (not shown). As previously explained, resource allocation device may be responsible for managing a number of agent devices (not shown) that also include one or more of processors **262**, at least in part. As noted above, module A **260** may be a homogenous module. As such, agent devices utilizing processors **262** may additionally utilize other hardware components located on other hardware modules (not shown). For example, an agent device utilizing one of processors **262** may also utilize a portion of main memory (not shown) mounted on a different module (not shown).

Module B **270** illustrates a decoupled heterogeneous hardware module. As shown, module B **270** includes twelve processors **272** and three memory banks **274**. Like module A **260**, module B **270** may support a resource allocation device and multiple agent devices. In the case of module B **270**, however, each resource allocation device and agent device may draw multiple types of hardware resources from the same physical module. Any processor **272** may utilize any memory bank **274**; in other words, the two resources are decoupled. In order to ensure efficient and effective usage, however, the resource allocation device may be responsible for assigning each agent device a specific share of one or more processors **272** and one or more memory banks **274**.

Module C **280** illustrates a coupled heterogeneous hardware module. As shown, module C **280** includes eighteen "compute cores" **286**. Each compute core **286** may include multiple hardware devices designed to work together as a unit. For example, each compute core **286** may include a processor and a memory bank (not shown). As such, each compute core may be referred to as a hardware element. Again, a resource allocation device and a number of agent devices may share the compute cores **286**. Because the various types of hardware resources are tightly coupled however, the resource allocation device may not necessarily manage the assignment of as many different types of resources to agent devices; instead, the resource allocation device may simply allocate each agent device a share of one or more computer cores **286**.

As will be described in further detail with respect to FIG. **3**, each module **260**, **270**, **280** may be designed such that any single hardware component may be deactivated while the remaining hardware components continue operation. As such, each module **260**, **270**, **280** may include power delivery circuitry that may be interrupted by a control signal for each mounted hardware component. Such control signal may be asserted by the resource allocation device, cloud computing gateway, and/or a separate device (not shown) adapted to manage the health of the hardware modules upon determining that a particular hardware component has failed or is otherwise no longer usable.

FIG. **3** illustrates an exemplary method **300** for handling a failed hardware component. For the purposes of explanation, method **300** will be assumed to be performed by a resource allocation device. It will be understood, however, that exemplary method **300** may additionally or alternatively be performed by the components of a cloud computing gateway such as cloud computing gateway **200**.

Exemplary method **300** may begin in step **305** and proceed to step **310** where the resource allocation device identifies a hardware component failure. In particular, the resource allocation device may determine that a hardware component has failed or will likely fail in the near future. In various embodiments, the resource allocation device may otherwise deem the hardware component unusable. Method **300** may then proceed to step **315** where the resource allocation device determines which agent devices currently include a share of the unusable hardware component. Then, in step **320**, the resource allocation device may reassign those agent devices to use other hardware components instead. After performance of this step, the failed component may no longer be used to provide hardware resources to any devices. At this point, the method **300** may optionally end and the resource allocation device may simply avoid using the failed component in the future.

In various embodiments, method **300** may proceed to step **325** where the resource allocation device may reconfigure the hardware module to power down the failed hardware component. This may have the effect of decreasing power consumption and, consequently, the cost of continued operation of the module as a whole. Then, in step **330**, the resource allocation device may report the failure to the cloud computing gateway. Using this report, the cloud computing gateway may proceed to redistribute agent devices at a higher level, among multiple resource allocation devices. It should be apparent that in embodiments where method **300** is performed by the cloud computing gateway itself, step **330** may not be present. Method **300** may then proceed to end in step **335**.

FIG. **4** illustrates an exemplary graph **400** of the failure rate of a hardware module over time. Line **410** shows that the hardware failure rate of a piece of hardware may generally follow the "bathtub curve" model over time. Near the beginning of the life of a hardware device, hardware failure may be relatively high due to the so-called "infant mortality rate." In other words, some hardware devices fail shortly after being put into operation due to latent defects. After surviving this phase, the hardware enjoys the majority of its useful life error free. Then, as the hardware ages, hardware failures increase in frequency due to "wear out" until, eventually, the hardware is completely unusable.

According to various aspects of the systems described herein, the useful life of a hardware component may be classified into various stages for hardware assignment and charging purposes. As shown, graph **400** is divided into five life phases. The brand new phase **421**, prime phase **422**, aging phase **423**, wear out phase **424**, and end of life phase **425**. It should be apparent that various alternative phase arrangements may be possible.

As part of assessing the current state of a hardware module, the cloud computing gateway and/or the resource allocation device may be adapted to determine the life phase in which the hardware module currently operates. This information can be determined using various useful life techniques known in the art as well as the historical failure rates of the module's constituent components. Subsequently, this information can be used to assign new agent devices to hardware modules based on the module's life phase. For example, a premium user may pay more for use of hardware currently operating in the prime phase **422**, where hardware failures are unlikely. As another example, different applications may have different failure tolerances. As such, a highly risk tolerant application may be assigned hardware operating in the brand new phase **421** or the wear out phase **424**. Further, the cloud computing gateway and/or the resource allocation device may entirely avoid modules that are in the end of life phase **425**.

FIG. **5** illustrates an exemplary data arrangement **500** for storing hardware status information. Exemplary data arrangement **500** may illustrate exemplary contents of module status storage **240** of exemplary hardware system **230**. Data arrangement may include a number of fields such as, for example, module field **510**, life phase field **520**, component field **530**, and failure rate field **540**.

Module field **510** may identify the module to which a particular module record applies. Life phase field **520** may indicate a most recently estimated life phase for the module. Component field **530** may identify a hardware component mounted on the module. Failure rate field **540** may indicate a most recently observed failure rate for the component. It will be noted that, while data arrangement **500** illustrates component records nested within module records, this may constitute an abstraction. Those of skill in the art will recognize that data arrangement **500** may actually be stored in a number of different manners. For example, data arrangement **500** may actually be stored as multiple tables, independently dedicated to hardware modules and hardware components, respectively.

As an example, module record **560** may indicate that module A is currently estimated to be in the third life phase, or aging phase **423**. Module record **560** may include a number of component sub-records **562**, **564**, **566**. Component sub-record **562** may indicate that CPU**1** has been observed to carry a 5% failure rate while component sub-record **564** may indicate that CPU**2** has been observed to carry a 50% failure rate. Module record **560** may include numerous additional component sub-records **566**. Exemplary module records **570**, **580** and exemplary component sub-records **572**, **573**, **574**, **576**, **578**, **582**, **584**, **586** indicate similar information, the meanings of which will be apparent in view of the foregoing description.

FIG. **6** illustrates an exemplary method **600** for controlling the consumption of hardware resources. For the purposes of explanation, method **600** will be assumed to be performed by the components of a cloud computing gateway such as cloud computing gateway **200**. It will be understood, however, that exemplary method **300** may additionally or alternatively be performed by a resource allocation device.

Method **600** may begin in step **605** and proceed to step **610** where the cloud computing gateway may effect the performance of a diagnostic test on a hardware component. For example, the cloud computing gateway may remove the component from the resource pool and/or initiate a new agent device on the component to perform one or more tests. Upon receiving results from the diagnostic test, the cloud computing gateway may determine, in step **615** whether the tests indicate that the component is no longer usable. In various embodiments, cloud computing gateway may determine that the component is "no longer usable" and has thus "failed" when continued operation of the component is no longer cost effective and/or capable of delivering service of acceptable quality with a low enough risk of failure. Thus, while a component may remain technically operational, the cloud computing gateway may deem it a failed component based on various additional factors.

If the component has failed, then the cloud computing gateway may migrate one or more agent devices to different hardware modules in step **620** to reduce the load on the module with the failed component. If the component has not yet failed or after the cloud computing gateway has migrated agent devices, method **600** may proceed to step **625** where the cloud computing gateway may update failure rate information associated with the tested component.

In step **630**, the cloud computing gateway may determine whether it should test additional components. For example, the cloud computing gateway may test all components on a module at the same time or may have a number of components scheduled for testing at a particular time. If additional components remain to be tested, method **600** may loop back to step **610**. Once all components to be tested have been tested, method **600** may proceed from step **630** to step **635**.

In step **635**, the cloud computing gateway may estimate the current life phase for a hardware module. This step may be performed according to various "useful life" techniques known to those of skill in the art and may be based on the failure rates of the hardware module's constituent components. For the purposes of explanation, it will be assumed that method **600** defines life phases in the manner detailed with respect to FIG. **4**. It will be apparent that various alternative life phase schemes may also be employed. After estimating the life phase of the module, the cloud computing gateway may update a module record and method **600**.

Next, in step **640**, the cloud computing gateway may determine whether the module is estimated to currently operate in life phase **5**. In other words, the cloud computing gateway may determine whether the module is in the "end of life" phase. If so, the cloud computing gateway may notify an administrator that the module is no longer usable and should be replaced in step **645**. If however, the module is in a different life phase, method **800** may proceed to step **650**. It should be noted that in various alternative embodiments, the cloud computing gateway may be adapted to notify an administrator that a module should be replaced at a different life phase such as, for example, in the "wearout phase." Further, in various embodiments, the life phase that elicits the replacement notification of step **645** may be configurable by and administrator based on a system wide or per-module basis. Various additional modifications to step **640** will be apparent to those of skill in the art.

In step **650**, the cloud computing gateway may project a failure date for the module. This step may be performed based on various methods known to those of skill in the art. For example, the cloud computing gateway may utilize a predictive model provided by a hardware manufacturer to estimate when the hardware module will meet a specified failure condition. This determination may be made based on various status information such as, for example, the life phase of the module and/or the failure rates of its constituent components.

The cloud computing gateway may proceed in step **655** to determine whether the projected failure date is sufficiently close to the target replacement date. In various embodiments, method **600** may require the two dates to coincide, while in other embodiments, method **600** may allow for a predetermined variance in the two dates. If the two dates are sufficiently close, the module is deemed to be on track to be consumed by the replacement date and the method **600** may proceed to end in step **655**.

If, however, the two dates are not sufficiently close, the cloud computing gateway may adjust various operating parameters of the hardware in step **660**. By adjusting the parameters, the cloud computing gateway may hasten or delay the failure of the hardware module such that the hardware module can now be expected to fail sufficiently close to the target replacement date. An exemplary process for achieving this functionality will be described in greater detail below with respect to FIG. **7**. After reconfiguring the hardware module, method **600** may proceed to end in step **665**.

FIG. **7** illustrates an exemplary method **700** for adjusting hardware parameters. For the purposes of explanation, method **700** will be assumed to be performed by the components of a cloud computing gateway such as cloud computing gateway **200**. It will be understood, however, that exemplary method **700** may additionally or alternatively be performed by a resource allocation device. Method **700** may correspond to step **660** of method **600**.

Method **700** may begin in step **705** and proceed to step **710**, where the cloud computing gateway may determine a parameter to adjust. For example, the cloud computing gateway may determine that it should adjust a clock frequency, cooling rate, and/or applied voltage. Alternatively or additionally, the cloud computing gateway may adjust an activation schedule, such that the component is active for a shorter or longer proportion of the time that the hardware module is operational. This determination may be made based on a predetermined parameter priority, a rule engine that applies a rule set for determining an appropriate parameter based on contextual data, or another method known to those of skill in the art.

Next, in step **715**, the cloud computing gateway may determine how the selected parameter should be adjusted. For example, the cloud computing gateway may utilize a predictive model associated with the selected parameter to determine what modification to the parameter will cause the module to meet the target replacement date. For example, the predictive model may indicate that overclocking the CPUs on the module by 200 MHz, reducing cooling by 10%, or increasing the proportion of time that each CPU is active by 10% will cause the module to fail closer to the target replacement date. Then, in step **725**, the cloud computing gateway may determine whether the parameter value is acceptable. The parameter value may be unacceptable, for example, if it is infeasible or impractical. For example, a module may not be able to safely increase the voltage past a certain level. As another example, overclocking a CPU may be impractical if the current load on the CPUs is already low. If the parameter value is unacceptable, the method may proceed to step **730**.

In step **730**, the cloud computing gateway may determine an alternative adjustment. For example, the cloud computing gateway may choose a parameter value somewhere between the current value and the value determined in step **715**. Alternatively, the cloud computing gateway may determine that the parameter should not be adjusted at all. Next, in step **735**, if the parameter is to be adjusted to an alternative value, the cloud computing gateway may effect such parameter adjustment. However, because an alternative adjustment was used, the module may not yet be configured to meet the target replacement date. Accordingly, method **700** may loop back to step **710** and repeat the process with a different parameter. As such, the cloud computing gateway may adjust multiple parameters to ensure that the module is consumed near the target replacement date.

Once the cloud computing gateway identifies an acceptable parameter adjustment that will be sufficient to cause the module to meet the target replacement date in step **725**, method **700** may proceed to step **740**. In step **740**, the cloud computing gateway may effect the parameter adjustment and method **700** may proceed to end in step **745**.

According to the foregoing, various embodiments enable a hardware architecture that limits the impact of a failed hardware resource on the total resources available. In particular, by providing hardware modules that can selectively deactivate or disuse failed hardware components, the hardware modules as a unit may continue operation. Further, by monitoring the status of such hardware modules and adjusting operation parameters of hardware components thereof, a hardware system can ensure that the hardware modules are fully consumed near a target replacement date.

It should be apparent from the foregoing description that various exemplary embodiments of the invention may be implemented in hardware, software, and/or firmware. Furthermore, various exemplary embodiments may be implemented as instructions stored on a machine-readable storage medium, which may be read and executed by at least one processor to perform the operations described in detail herein. A machine-readable storage medium may include any mechanism for storing information in a form readable by a machine, such as a personal or laptop computer, a server, or other computing device. Thus, a tangible and non-transitory machine-readable storage medium may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and similar storage media.

It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in machine readable media and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

Although the various exemplary embodiments have been described in detail with particular reference to certain exemplary aspects thereof, it should be understood that the invention is capable of other embodiments and its details are capable of modifications in various obvious respects. As is readily apparent to those skilled in the art, variations and modifications can be effected while remaining within the spirit and scope of the invention. Accordingly, the foregoing disclosure, description, and figures are for illustrative purposes only and do not in any way limit the invention, which is defined only by the claims.

What is claimed is:

**1**. A method performed by a hardware management device for enabling incremental failure of a hardware system, the hardware system including a hardware module, the hardware module including a circuit board upon which a plurality of hardware components is mounted, the method comprising:
- identifying a hardware failure of a failed component of the plurality of hardware components;
- determining a set of agent devices currently configured to utilize the failed component;
- for at least one agent device of the set of agent devices, reconfiguring the agent device to utilize a working component of the plurality of hardware components in place of the failed component; and
- deactivating the failed component, wherein other hardware components of the plurality of hardware components remain in operation.

**2**. The method of claim **1**, further comprising reconfiguring the hardware module to power down the failed component while continuing to provide power to at least one other component of the plurality of hardware components.

**3**. The method of claim **1**, wherein all hardware components mounted on the circuit board are of a single type of hardware component.

**4**. The method of claim **1**, wherein the hardware management device comprises a hypervisor and wherein the hardware management device utilizes at least one component of the plurality of hardware components to operate.

**5**. The method of claim **1**, wherein the hardware management device comprises a cloud computing gateway device and wherein:
- the hardware management device manages a plurality of hypervisors; and
- a first hypervisor of the plurality of hypervisors manages the plurality of hardware components.

**6**. The method of claim **5**, further comprising:
- for at least one agent device of the set of agent devices, reconfiguring the agent device to be managed by a second hypervisor of the plurality of hypervisors.

**7**. A hardware system capable of incremental hardware failure, the hardware system comprising:
- a circuit board;
- a plurality of hardware components mounted on the circuit board;
- at least one agent device configured to utilize at least one hardware component of the plurality of hardware components; and
- a management device that, during run time, deactivates at least one hardware component of the plurality of hardware components while at least one remaining component of the plurality of hardware components remains in operation,
- wherein the management device deactivates the at least one hardware component of the plurality of hardware components in response to determining that the at least one hardware component has failed.

**8**. The hardware system of claim **7**, wherein, in deactivating the at least one hardware component, the management device reconfigures the circuit board to power down the at least one component.

**9**. The hardware system of claim **7**, wherein the management device includes a hypervisor and the management device utilizes at least one hardware component of the plurality of hardware components.



**10**. The hardware system of claim **7**, wherein all hardware components mounted on the circuit board are of the same type.

**11**. The hardware system of claim **7**, wherein, in deactivating the at least one hardware component, the management device:
- identifies a set of agent devices configured to utilize the at least one hardware component; and
- reconfigures at least one agent device of the set of agent devices to utilize the at least one remaining component instead of the at least one hardware component.

**12**. A tangible and non-transitory machine-readable storage medium encoded with instructions for execution by a hardware management device for enabling incremental failure of a hardware system, the hardware system including a hardware module, the hardware module including a circuit board upon which a plurality of hardware components is mounted, the tangible and non-transitory machine-readable storage medium comprising:
- instructions for identifying a hardware failure of a failed component of the plurality of hardware components;
- instructions for determining a set of agent devices currently configured to utilize the failed component;
- instructions for, for at least one agent device of the set of agent devices, reconfiguring the agent device to utilize a working component of the plurality of hardware components in place of the failed component; and
- instructions for deactivating the failed component, wherein other hardware components of the plurality of hardware components remain in operation.

**13**. The tangible and non-transitory machine-readable storage medium of claim **12**, instructions for reconfiguring the hardware module to power down the failed component while continuing to provide power to at least one other component of the plurality of hardware components.

**14**. The tangible and non-transitory machine-readable storage medium of claim **12**, wherein all hardware components mounted on the circuit board are of a single type of hardware component.

**15**. The tangible and non-transitory machine-readable storage medium of claim **12**, wherein the hardware management device comprises a hypervisor and wherein the hardware management device utilizes at least one component of the plurality of hardware components to operate.

**16**. The tangible and non-transitory machine-readable storage medium of claim **12**, wherein the hardware management device comprises a cloud computing gateway device and wherein:
- the hardware management device manages a plurality of hypervisors; and
- a first hypervisor of the plurality of hypervisors manages the plurality of hardware components.

**17**. The tangible and non-transitory machine-readable storage medium of claim **16**, further comprising:
- instructions for, for at least one agent device of the set of agent devices, reconfiguring the agent device to be managed by a second hypervisor of the plurality of hypervisors.

**18**. A method performed by a hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the method comprising:
- projecting a failure date for the hardware module;

determining whether the projected failure date is acceptable based on a target replacement date for the hardware module;

if the projected failure date is not acceptable:

determining at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and

applying the at least one parameter adjustment to the least one hardware component of the plurality of hardware components.

**19**. The method of claim **18**, wherein the at least one parameter adjustment is selected to cause the hardware module to fail sooner than the projected failure date.

**20**. The method of claim **18**, further comprising:

estimating a current life phase for the module based on a failure rate for each of the plurality of hardware components;

wherein the step of projecting a failure date for the hardware module is performed based on the current life phase of the module.

**21**. The method of claim **20**, wherein the hardware management device manages a plurality of hardware modules and each hardware module is associated with a current life phase, the method further comprising:

receiving a request for establishment of an agent device;

determining a life phase permission associated with the request, wherein the life phase permission indicates that a module having a permitted life phase should be used for fulfilling the request;

selecting a hardware module of the plurality of hardware modules, wherein the selected hardware module is associated with the permitted life phase; and

fulfilling the request using the selected hardware module.

**22**. The method of claim **18**, wherein the step of projecting a failure date for the hardware module comprises projecting a date at which a failure condition will be met, wherein the failure condition is met when less than a configured number of hardware components remain operational.

**23**. The method of claim **18**, further comprising determining a failure rate of at least one of the plurality of hardware components, wherein the step of projecting a failure date for the hardware module is performed based on the failure rate of at least one of the plurality of hardware components.

**24**. The method of claim **18**, wherein the at least one parameter adjustment comprises an adjustment to at least one of the following: a cooling rate, a voltage, a clock frequency, and an activation schedule.

**25**. A hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the hardware management device comprising:

a consumption policy engine configured to:

project a failure date for the hardware module, and

determine whether the projected failure date is acceptable based on a target replacement date for the hardware module; and

a parameter adjuster that is configured to, if the projected failure date is not acceptable:

determine at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and

apply the at least one parameter adjustment to the at least one hardware component of the plurality of hardware components.

**26**. The hardware management device of claim **25**, wherein parameter adjuster selects a parameter adjustment to cause the hardware module to fail sooner than the projected failure date.

**27**. The hardware management device of claim **25**, further comprising a diagnostic engine that estimates a current life phase for the module based on a failure rate for each of the plurality of hardware components, wherein, the consumption policy engine projects the failure date for the hardware module based on the current life phase of the module.

**28**. The hardware management device of claim **27**, wherein the hardware management device manages a plurality of hardware modules and each hardware module is associated with a current life phase, the hardware management device further comprising:

a request handler configured to:

receive a request for establishment of an agent device;

determine a life phase permission associated with the request, wherein the life phase permission indicates that a module having a permitted life phase should be used for fulfilling the request;

select a hardware module of the plurality of hardware modules, wherein the selected hardware module is associated with the permitted life phase; and

fulfill the request using the selected hardware module.

**29**. The hardware management device of claim **25**, wherein the consumption policy engine projects the failure date for the hardware module by projecting a date at which a failure condition will be met, wherein the failure condition is met when less than a configured number of hardware components remain operational.

**30**. The hardware management device of claim **25**, wherein the at least one parameter adjustment comprises an adjustment to at least one of the following: a cooling rate, a voltage, a clock frequency, and an activation schedule.

**31**. A tangible and non-transitory machine-readable storage medium encoded with instructions for execution by a hardware management device for controlling consumption of a hardware module, the hardware module including a plurality of hardware components, the tangible and non-transitory machine-readable storage medium comprising:

instructions for projecting a failure date for the hardware module;

instructions for determining whether the projected failure date is acceptable based on a target replacement date for the hardware module;

instructions for, if the projected failure date is not acceptable:

determining at least one parameter adjustment for at least one hardware component of the plurality of hardware components, wherein the at least one parameter adjustment is selected to move the projected failure date closer to the target replacement date, and

applying the at least one parameter adjustment to the at least one hardware component of the plurality of hardware components.

**32**. The tangible and non-transitory machine-readable storage medium of claim **31**, wherein the at least one parameter adjustment is selected to cause the hardware module to fail sooner than the projected failure date.

**33**. The tangible and non-transitory machine-readable storage medium of claim **31**, further comprising:

instructions for estimating a current life phase for the module based on a failure rate for each of the plurality of hardware components;

wherein the instructions for projecting a failure date for the hardware module operate based on the current life phase of the module.

**34**. The tangible and non-transitory machine-readable storage medium of claim **33**, wherein the hardware management device manages a plurality of hardware modules and each hardware module is associated with a current life phase, the tangible and non-transitory machine-readable storage medium further comprising:

instructions for receiving a request for establishment of an agent device;

instructions for determining a life phase permission associated with the request, wherein the life phase permission indicates that a module having a permitted life phase should be used for fulfilling the request;

instructions for selecting a hardware module of the plurality of hardware modules, wherein the selected hardware module is associated with the permitted life phase; and

instructions for fulfilling the request using the selected hardware module.

**35**. The tangible and non-transitory machine-readable storage medium of claim **31**, wherein the instructions for projecting a failure date for the hardware module comprise instructions for projecting a date at which a failure condition will be met, wherein the failure condition is met when less than a configured number of hardware components remain operational.

**36**. The tangible and non-transitory machine-readable storage medium of claim **31**, further comprising instructions for determining a failure rate of at least one of the plurality of hardware components, wherein the instructions for projecting a failure date for the hardware module operate based on the failure rate of at least one of the plurality of hardware components.

**37**. The tangible and non-transitory machine-readable storage medium of claim **31**, wherein the at least one parameter adjustment comprises an adjustment to at least one of the following: a cooling rate, a voltage, a clock frequency, and an activation schedule.

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